SIGNALS OF DECONFINEMENT TRANSITION IN NUCLEUS-NUCLEUS COLLISIONS

Mark I. Gorenstein
Bogolyubov Institute for Theoretical Physics, Kiev, Ukraine
mark@mgor.kiev.ua

Abstract We discuss the energy dependence of hadron production in relativistic nucleus-nucleus collisions. Several ‘anomalies’ in the energy dependence have been predicted as signals of the deconfinement phase transition and three of these signals are observed at the CERN SPS indicating that the onset of deconfinement in Pb+Pb collisions is located at about 30 A·GeV.

Keywords: Nucelus-nucleus collisions, energy scan programme, quark-gluon plasma.

1. Introduction

The data on heavy nucleus-nucleus (A+A) collisions suggested that there is a significant change in the energy dependence of the pion and strangeness yields which is located between the top AGS (11 A·GeV) and SPS (158 A·GeV) energies. Based on the statistical approach it was speculated that the change is related to the onset of deconfinement at the early stage of A+A collisions, and a simplified quantitative model was developed, the Statistical Model of the Early Stage (SMES) [1]. The SMES predicted a sharp maximum in the multiplicity ratio of strange hadrons to pions at the begining of the transition region. This prediction triggered a new experimental programme at the SPS – the energy scan programme – in which the NA49 experiment recorded central Pb+Pb collisions at several energies: the results from the run at 40, 80 and 158 A·GeV are published [2], the results from the 30 A·GeV run were shown for the first time at the conference SQM03 [3], the data at 20 A·GeV are still being analysed. The energy scan program at the CERN SPS results an observation of several ‘anomalies’ in the energy dependence of hadron production in the same domain of the collision energy. These ‘anomalies’ are interpreted as signals of the deconfinement phase transition in A+A collisions. In this report we review the physical arguments which lead us to the proposed signals as well as discuss their experimental status.

2. Signals of Deconfinement: Model Predictions

Originally, two signals of the deconfinement phase transition were proposed within SMES [1]: the energy dependence of the mean pion and strangeness multiplicities. Recently, two new signals were suggested within SMES: the energy dependence of the inverse slope of the transverse mass spectrum of kaons [4] and the energy dependence of properly filtered multiplicity fluctuations [5, 6].

An exact nature of the deconfinement phase transition is still debated. On the other hand, it is rather well established in the lattice QCD at zero baryonic chemical potential that very strong changes of the energy density ε take place in a narrow temperature interval $\Delta T = 5 \div 10$ MeV. Within this temperature interval the energy density changes by about an order of magnitude, whereas the pressure remains approximately unchanged. One may refer to this temperature interval as a 'generalised mixed phase'.

The Pion Multiplicity. The majority of all particles produced in high energy interactions are pions. Thus, pions carry basic information on the entropy created in the collisions. On the other hand, the entropy production should depend on the form of matter present at the early stage of collisions. A deconfined matter is expected to lead to the final state with higher entropy than that created by a confined matter. Consequently, it is natural to expect that the onset of creation of a deconfined matter should be signalled by an enhancement of the pion production. Clearly, a trivial dependence of the pion multiplicity on the size of colliding nuclei should be removed and thus a relevant observable is the ratio of the mean pion multiplicity $\langle\pi\rangle$ to the mean number of wounded nucleons $\langle N_W\rangle$. The simple intuitive argumentation can be further quantified within SMES assuming the generalised Fermi–Landau initial conditions: the initial volume is Lorenz-contracted, $V \propto (\sqrt{s})^{-1}$ ($\sqrt{s}$ is the c.m.s. energy of the nucleon pair), the initial energy density is given by $\varepsilon \propto gT^4 \propto (\sqrt{s} - 2m_N) \cdot \sqrt{s}$ (T is the initial temperature and g is an effective number of internal degrees of freedom at the early stage, m_N is the nucleon mass). The pion multiplicity is proportional to the initial entropy, and the $\langle\pi\rangle/\langle N_W\rangle$ ratio can be thus calculated outside the transition region as

$$\langle\pi\rangle/\langle N_W\rangle \ \propto V\, g\, T^3 \ \propto g^{1/4}(\sqrt{s} - m_N)^{3/4}(\sqrt{s})^{-1/4} \ \equiv \ g^{1/4}\, F\, . \quad (1)$$

Therefore, the $\langle\pi\rangle/\langle N_W\rangle$ ratio increases linearly with F outside the transition region, and the slope parameter is proportional to $g^{1/4}$ [7]. In the transition region, a steepening of the pion energy dependence is predicted, because of activation of partonic degrees of freedom, i.e. an effective number of internal degrees of freedom in the quark gluon plasma (QGP) is larger than in the hadron gas (HG): $g_{QGP} > g_{HG}$.

The Strangeness to Pion Ratio. The energy dependence of the strangeness to entropy ratio is a crucial signal of the deconfinement due to its weak dependence on the assumed initial conditions. Within SMES at low collision energies, when the confined matter is produced, the strangeness to entropy ratio steeply increases with collision energy. Due to a low temperature at the early stage ($T < T_C \cong 170$ MeV) and the high mass of the carriers of strangeness ($m_S \cong 500$ MeV, the kaon mass) the total strangeness is $\propto \exp(-m_S/T)$. On the other hand, the total entropy is approximately $\propto T^3$. Therefore, the strangeness to pion ratio is $\propto \exp(-m_S/T) \cdot T^{-3}$ in the HG and strongly increases with the collision energy. When the transition to a deconfined matter is crossed ($T > T_C$), the mass of the strangeness carriers is significantly reduced ($m_s = 130 \div 170$ MeV, the strange quark mass). Due to the low mass ($m_s < T$) the strangeness yield becomes (approximately) proportional to the entropy (both are proportional to T^3), and the strangeness to entropy (or pion) ratio becomes independent of energy in the QGP. This leads to a "jump" in the energy dependence from the larger value for confined matter at T_C to the value for deconfined matter. Thus, within the SMES, the non-monotonic energy dependence of the strangeness to entropy ratio is followed by a saturation at the deconfined value which is a direct consequence of the onset of deconfinement taking place at about 30 AGeV [1].

The Inverse Slope of Transverse Mass Spectra. We discuss another well known observable, which may be sensitive to the onset of deconfinement, the transverse momentum, p_T, spectra of produced hadrons. It was suggested by Van Hove [8] more than 20 years ago to identify the deconfinement phase transition in high energy proton-antiproton interactions with a plateau-like structure of the average transverse momentum as a function of the hadron multiplicity[1]. According to the general concepts of the hydrodynamical approach the hadron multiplicity reflects the entropy, whereas the transverse hadron activity reflects the combined effects of temperature and collective transverse expansion. The entropy is assumed to be created at the early stage of the collision and is approximately constant during the hydrodynamic expansion. The multiplicity is proportional to the entropy, $S = s \cdot V$, where s is the entropy density and V is the effective volume occupied by particles. During the hydrodynamic expansion, s decreases and V increases with $s \cdot V$ being approximately constant. Large multiplicity at high energies means a large entropy density at the beginning of the expansion (and consequently a larger volume at the end). Large value of s at the early stage of the collisions means normally high temperature T at this stage. This, in turn, leads to an increase of the transverse

[1]In the original suggestion [8] the correlation between average transverse momentum and hadron multiplicity was discussed for $p + \bar{p}$ at fixed collision energy. Today we have an advantage to use central A+A collisions at different energies [4].

hadron activity, a flattening of the transverse momentum spectrum. Therefore, with increasing collision energy one expects to observe an increase of both the hadron multiplicity and the average transverse momentum per hadron. However, presence of the deconfinement phase transition would change this correlation. In the phase transition region, the initial entropy density (and hence the final hadron multiplicity) increases with the collision energy, but temperature $T = T_C$ and pressure $p = p_C$ remain constant. The equation of state (EoS) presented in a form $p(\varepsilon)/\varepsilon$ versus ε shows a minimum (the 'softest point' [9]) at the boundary of the *generalised mixed phase* and the QGP. Consequently the shape of the p_T spectrum is approximately independent of the multiplicity or the collision energy. The transverse expansion effect may even decrease when crossing the transition region [8]. Thus one expects an 'anomaly' in the energy dependence of the transverse hadron activity: the average transverse momentum increases with the collision energy when the early stage matter is either in a pure confined or in a pure deconfined phase, and it remains approximately constant when the matter is in a mixed phase [4, 8]. A simplified picture with $T = T_C$ inside the mixed phase is changed if the created early stage matter has a non-zero baryonic density. It was however demonstrated [10] that the main qualitative features ($T \cong const$, $p \cong const$, and a minimum of the function $p(\varepsilon)/\varepsilon$ versus ε) are present also in this case. In the SMES model [1], which correctly predicted energy dependence of the pion and strangeness yields, the modification of the EoS due to the deconfinement phase transition is located between 30 and about 160 A·GeV. Thus an anomaly in the energy dependence of the transverse hadron activity may be expected in this energy range.

The energy density at the early stage increases with increasing collision energy. At low and high energies, when a pure confined or deconfined phase is produced, this leads to an increase of the initial temperature and pressure. This, in turn, results in an increase of the transverse expansion of a matter and consequently a flattening of the transverse mass spectra of final state hadrons. The experimental data on the transverse mass spectra ($m_T = (m^2 + p_T^2)^{1/2}$, m is a particle mass) are usually parametrized by a simple exponential dependence:

$$\frac{dN}{m_T dm_T} \;=\; C\;\exp\left(-\,\frac{m_T}{T^*}\right)\;, \tag{2}$$

where the inverse slope parameter T^* is sensitive to both the thermal and collective motion in the transverse direction. In the parameterisation (2), the shape of the m_T spectrum is fully determined by a single parameter, the inverse slope T^*. In particular, the average transverse mass $\langle m_T \rangle$ can be expressed as:

$$\langle m_T \rangle \;=\; T^* \;+\; m \;+\; \frac{(T^*)^2}{m \;+\; T^*}\;. \tag{3}$$

Hydrodynamical transverse flow with collective velocity v_T modifies the Boltzmann m_T-spectrum of hadrons. At low transverse momenta, it leads to the

result (T_{kin} is a kinetic freeze-out temperature):

$$T^*_{low-p_T} \ = \ T_{kin} \ + \ \frac{1}{2} m \, v_T^2 \ . \tag{4}$$

A linear mass dependence (4) of T^* is supported by the data for hadron spectra at small p_T. However, for $p_T >> m$ the hydrodynamical transverse flow leads to the mass-independent blue-shifted 'temperature':

$$T^*_{high-p_T} \ = \ T_{kin} \ \cdot \ \sqrt{\frac{1+v_T}{1-v_T}} \ . \tag{5}$$

A simple one parameter exponential fit (2) is quite accurate up to $m_T - m \cong 1$ GeV for K^+ and K^- mesons in A+A collisions at all energies. This means that $T^*_{low-p_T} \approx T^*_{high-p_T}$ for kaons and the energy dependence of the average transverse mass $\langle m_T \rangle$ (3) and the average transverse momentum $\langle p_T \rangle$ for kaons is qualitatively the same as that for the parameter T^*. Note that a simple exponential fit (2) neither works for light π-mesons, $T^*_{low-p_T} < T^*_{high-p_T}$, nor for heavy (anti)protons and (anti)lambdas, $T^*_{low-p_T} > T^*_{high-p_T}$. This means that the average transverse masses, $\langle m_T \rangle$, and their energy dependence for these hadrons are not connected to the behavior of the slope parameters in the simple way described by Eq. (3): one should separately consider both $T^*_{low-p_T}$ and $T^*_{high-p_T}$ slopes (see Refs. [11, 12] for details).

The Dynamical Event-by-Event Fluctuations. In thermodynamics, the energy E, volume V and entropy S are related to each other through the EoS. Thus, various values of the energy of the initial equilibrium state lead to different, but uniquely determined, initial entropies. When the collision energy is fixed, the energy, which is used to hadron production still fluctuates. These fluctuations of of the inelastic energy are caused by the fluctuations in the dynamical process which leads to the particle production. They are called the dynamical energy fluctuations [5]. Clearly the dynamical energy fluctuations lead to the dynamical fluctuations of any macroscopic parameter of the matter, X, like its entropy and strangeness content. The relation between the dynamical energy fluctuations and dynamical fluctuations of the macroscopic parameter X is given by the EoS. Consequently, simultaneous measurements of the event-by-event fluctuations of both the energy and the parameter X yield information on the EoS. Since EoS shows an anomalous behavior in the phase transition region, the anomaly should be visible in the ratio of entropy to energy fluctuations [5].

According to the first and the second principles of thermodynamics the entropy change δS is given as $T\delta S = \delta E + p\delta V$. If we fix the collision geometry, choosing e.g. only a sample of central A+A collisions, we can expect $\delta V \cong 0$. Within SMES the ratio of entropy to energy fluctuations can be then easily

calculated and presented as a simple function of the p/ε ratio [5]:

$$R_e \equiv \frac{(\delta S)^2/S^2}{(\delta E)^2/E^2} = \left(1 + \frac{p}{\varepsilon}\right)^{-2} . \tag{6}$$

Thus it is easy to predict a qualitative dependence of the R_e ratio on the collision energy. Within the model, the confined matter, which is modelled as an ideal gas, is created at the collision early stage below the energy of 30 A·GeV. In this domain, the ratio p/ε, and consequently the R_e ratio, are approximately independent of the collision energy and equal about 1/3 and 0.56, respectively. The model assumes that the deconfinement phase–transition is of the first order. Thus, there is the mixed phase region, corresponding to the energy interval 30÷60 A·GeV. At the end of the mixed phase the p/ε ratio reaches minimum (the "softest point" of EoS [9]). Thus in the transition energy range the R_e ratio increases and reaches its maximum, $R_e \approx 0.8$, at the end of the transition domain. Further on, in the pure deconfined phase, which is represented by an ideal quark-gluon gas under bag pressure, the p/ε ratio increases and approaches its asymptotic value 1/3 at the highest SPS energy 160 A·GeV. An estimate of entropy fluctuations can be obtained form the analysis of multiplicity fluctuations as proposed in [5].

At the stage of particle freeze-out, the system's entropy is related to the mean particle multiplicity. We assume that the multiplicity of negatively charged hadrons is proportional to the system entropy, $S \propto \overline{N}_-$. Thus the initial entropy fluctuations are transformed into the the fluctuations of the *mean* multiplicity. It is important to distinguish these dynamical fluctuations of $\overline{N}_-$ formed at the initial stage of A+A reaction, from the statistical fluctuations of N_- around $\overline{N}_-$ at the freeze-out (see Ref. [5] for details).

In Ref. [6] we study within the SMES the energy dependence of the dynamical strangeness fluctuations caused by the dynamical energy fluctuations. We define $\overline{N}_s$ as a total number of strange quark-antiquark pairs created in A+A collision, and consider the fluctuation ratio:

$$R_s = \frac{(\delta \overline{N}_s)^2/\overline{N}_s^2}{(\delta E)^2/E^2} . \tag{7}$$

When $T \rightarrow \infty$ the system is in the QGP phase. Strange (anti)quarks can be considered as massless and the bag constant can be neglected. Then $\varepsilon \propto T^4$ and $n_s \propto T^3$ and consequently $d\varepsilon/\varepsilon = 4 \cdot dT/T$ and $dn_s/n_s = 3 \cdot dT/T$, which result in $R_s = (3/4)^2 \cong 0.56$. In the confined phase, $T < T_C$, the energy density is still approximately given by $\propto T^4$ due to the dominant contributions of non-strange hadron constituents. However, the deppendence of the strangeness density on T is dominated in this case by the exponential factor, $n_s \propto \exp(-m_S/T)$, as $T << m_S \cong 500$ MeV. Therefore, at small

T one finds $d\varepsilon/\varepsilon = 4 \cdot dT/T$ and $dn_s/n_s = m_S \cdot dT/T^2$, so that the ratio $R_s = m_S/(4T)$ decreases with T. The strangeness density n_s is small and goes to zero at $T \to 0$, but the fluctuation ratio R_s (7) is large and goes to infinity at zero temperature limit.

3. Signals of Deconfinement: Experimental Results

The Pion Kink. A recent compilation of the data on the pion multiplicity in central Pb+Pb (Au+Au) collisions and p+p interactions is shown in Fig. 1.

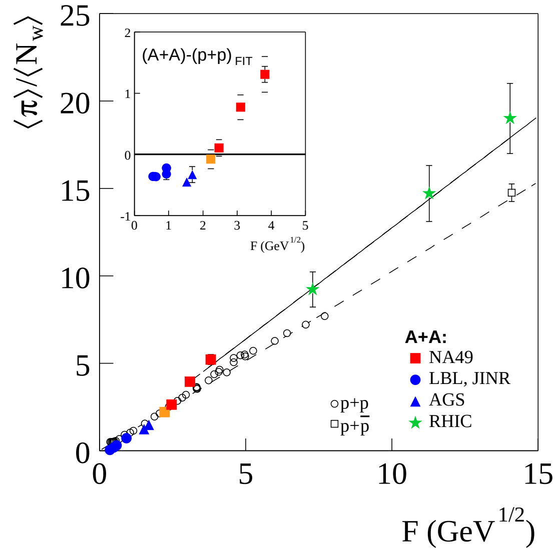


Figure 1 . The dependence of the total pion multiplicity per wounded nucleon, $\langle\pi\rangle/\langle N_W\rangle$, on the Fermi's energy measure $F \equiv (\sqrt{s} - 2m_N)^{3/4} \cdot (\sqrt{s})^{-1/4}$ for central A+A collisions (closed symbols) and inelastic $p + p(\overline{p})$ interactions (open symbols). The lines are calculated with SMES [1]. The dashed line indicates a fit of the form $a \cdot F$ to the $p + p(\overline{p})$ data ($a = 1.01 \pm 0.04$ GeV$^{-1/2}$). The solid line corresponds to the fit of A+A data for initial energy above 40 A·GeV ($a = 1.36 \pm 0.03$ GeV$^{-1/2}$).

One observes that the mean pion multiplicity per wounded nucleon in $p+p(\overline{p})$ interactions is approximately proportional to F. For central A+A collisions, the dependence is more complicated and cannot be fitted by a single linear function. Below 40 A·GeV the ratio $\langle\pi\rangle/\langle N_W\rangle$ in A+A collisions is lower than in $p+p$ interactions (pion suppression), while at higher energies $\langle\pi\rangle/\langle N_W\rangle$ is larger in A+A collisions than in $p + p(\overline{p})$ interactions (pion enhancement). In the region between the AGS and the low SPS energy, the slope changes from $a \cong 1.01$ GeV$^{-1/2}$ (the dashed line in Fig. 1) to $a \cong 1.36$ GeV$^{-1/2}$ (the full line in Fig. 1).

The measured increase of the slope for A+A collisions, by a factor of about 1.3, is interpreted within the SMES as due to an increase of the effective number of the internal degrees of freedom by a factor of $(1.3)^4 \cong 3$ and is caused by the creation of a transient state of deconfined matter at energies higher than 30 A·GeV. A transition from the pion suppression [13] to pion enhancement is demonstrated more clearly in the insert of Fig. 1, where the difference between $\langle\pi\rangle/\langle N_W\rangle$ for A+A collisions and the straight line parametrisation of the $p+p$ data is plotted as a function of F up to the highest SPS energy.

The Strange Horn. One can argue that the strangeness to entropy ratio is closely proportional to the two ratios directly measured in experiments: the $\langle K^+\rangle/\langle\pi^+\rangle$ ratio and the $E_S = (\langle\Lambda\rangle + \langle K + \overline{K}\rangle)/\langle\pi\rangle$ ratio. The energy dependence of both ratios is plotted in Fig. 2 for central Pb+Pb (Au+Au) collisions and p+p interactions.

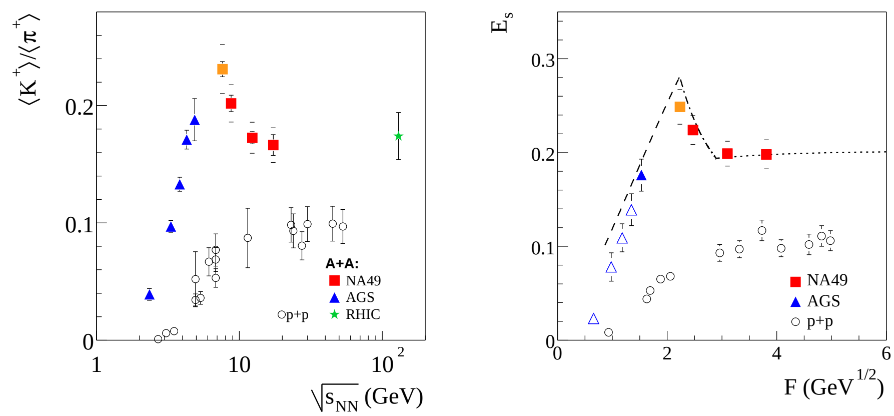


Figure 2. The dependence of the $\langle K^+\rangle/\langle\pi^+\rangle$ (left) and E_S (right) ratios on the collision energy for central A+A collisions (closed symbols) and inelastic $p + p$ interactions (open symbols). The predictions of SMES [1] for the E_S ratio are shown by a line. Different line styles indicate predictions in the energy domains in which the confined matter (dashed line), the mixed phase (dashed–dotted line) and the deconfined matter (dotted line) are created at the early stage of the A+A collision.

For p+p interactions both ratios show monotonic increase with energy. However, very different behavior is observed for central Pb+Pb (Au+Au) collisions. The steep threshold rise of the ratio characteristic for confined matter then settles into saturations at the level expected for deconfined matter. In the transition region (at low SPS energies) a sharp maximum is observed caused by a higher strangeness to entropy ratio in the confiend matter than in the deconfiend matter. As seen in Fig. 2 the measured dependence is consistent with that expected within the SMES.

The Step in Slopes. The energy dependence of the inverse slope parameter fitted to the K^+ and K^- transverse mass spectra for central Pb+Pb (Au+Au) collisions is shown in Fig. 3 [4]. The striking features of the data can be summarised and interpreted as follows. The T^* parameter increases strongly with collision energy up to the lowest (30 A·GeV) SPS energy point. This is an energy region where the creation of confined matter at the early stage of the collisions is expected. Increasing collision energy leads to an increase of the early stage temperature and pressure. Consequently the transverse activity of produced hadrons, measured by the inverse slope parameter, increases with increasing energy. The T^* parameter is approximately independent of the collision energy in the SPS energy range. In this energy region the transition

between confined and deconfined matter is expected to be located. The resulting modification of the equation of state "suppresses" the hydrodynamical transverse expansion and leads to the observed plateau structure in the energy dependence of the T^* parameter. At higher energies (RHIC data), T^* again increases with the collision energy. The equation of state at the early stage becomes again stiff, the early stage temperature and pressure increase with collision energy, and this results in increase of T^* too.

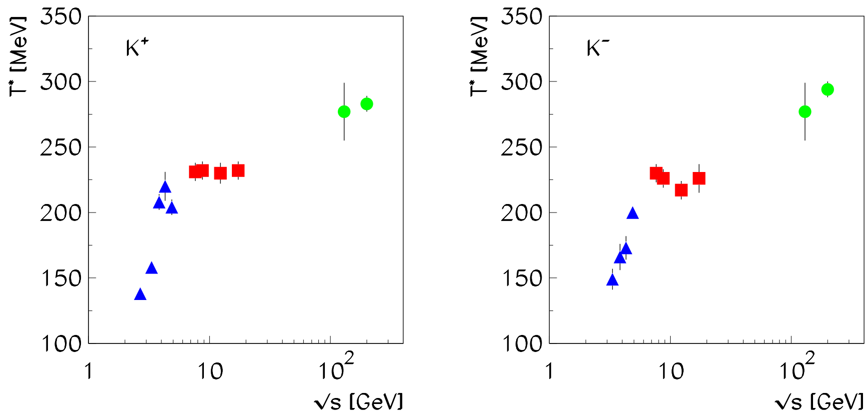


Figure 3. The energy dependence of the inverse slope parameter T^* for K^+ (left) and K^- (right) mesons (see Ref. [4]) produced at mid-rapidity in central Pb+Pb (Au+Au) collisions at AGS (triangles), SPS (squares) and RHIC (circles) energies.

Kaons are the best and unique particles among measured hadron species for observing the effect of the modification of the equation of state due to the onset of the deconfinement in hadron transverse momentum spectra. The arguments are the following.

1). The kaons m_T–spectra are only weakly affected by the hadron rescattering and resonance decays during the post-hydrodynamic hadron cascade at the SPS and RHIC energies [11].

2). A simple one parameter exponential fit (3) is quite accurate for kaons in central A+A collisions at all energies. This simplifies strongly an analysis of the experimental data.

3). The high quality data on m_T-spectra of K^+ and K^- mesons in central Pb+Pb (Au+Au) collisions are available in the full range of relevant energies.

The Dynamical Event-by-Event Fluctuations. The ratios of entropy to energy (6) and strangeness to energy (7) dynamical fluctuations calculated within SMES are presented in Fig. 4. We find a non-monotonic energy dependence of R_e with a maximum at the boundary between the mixed phase and the QGP [5]. A pronounced minimum-structure is expected in the dependence of R_s on

the collision energy [6]. It is located at $30 \div 60$ A·GeV, where the mixed phase is created at the early stage of A+A collision.

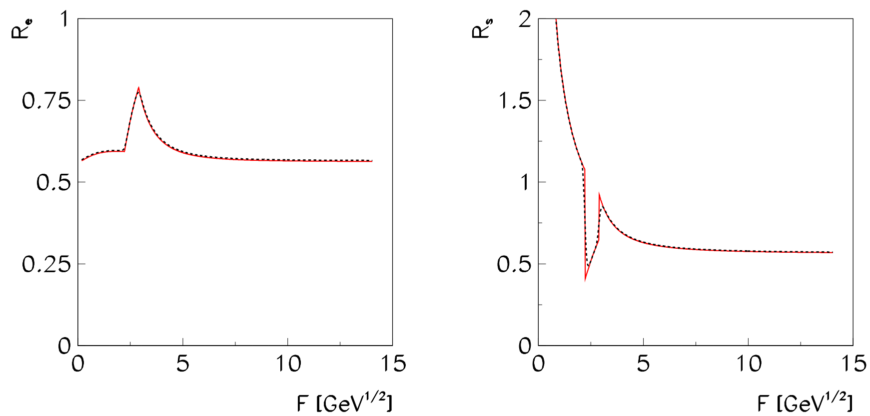


Figure 4. The collision energy dependence of the relative entropy to energy fluctuations R_e (6), left (see Ref. [5]), and strangeness to energy fluctuations R_s (7), right (see Ref. [6]), calculated within SMES.

The experimental data on the energy dependnece of R_e and R_s ratio are not yet available. Both entropy and strangeness fluctuation measures, R_e and R_s, show anomalous behavior in the transition region: the maximum is expected for R_e and the minimum for R_s. Consequetly, even a stronger anomaly is predicted for the ratio:

$$R_{s/e} \equiv \frac{R_s}{R_e} = \frac{(\delta \overline{N}_s)^2/\overline{N}_s^2}{(\delta \overline{N}_-)^2/\overline{N}_-^2} \,. \tag{8}$$

Experimental measurements of $R_{s/e}$ may be easier than the measurements of R_e and R_s because the ratio $R_{s/e}$ requires measurements of particle multiplicities only, whereas both R_e and R_s involve also measurements of particle energies.

4. Conclusions

The energy scan program at the CERN SPS together with the measurements at lower (LBL, JINR, SIS, BNL AGS) and higher (BNL RHIC) energies yielded systematic data on energy dependence of hadron production in central Pb+Pb (Au+Au) collisions. Predicted signals of the deconfinement phase transition, namely anomalies in the energy dependence of hadron production – the *pion kink* [1, 7], *strange horn* [1] and the *step in slope* of K-mesons [4] – are simultaneously observed in the same domain of the low SPS energies and presented in the left panel of Fig. 5.

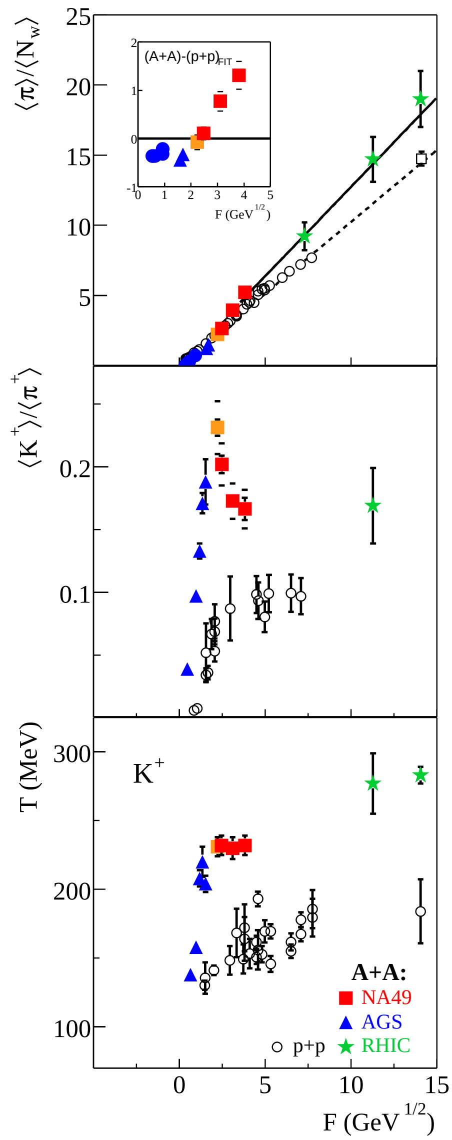
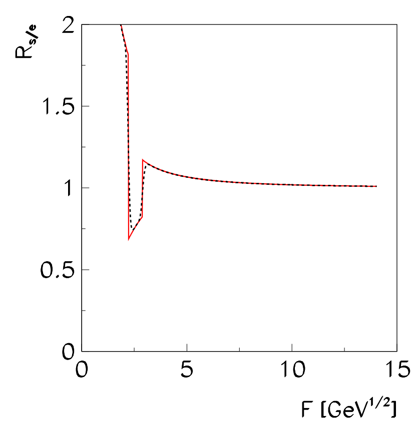


Figure 5 . The collision energy dependence of $\langle \pi \rangle / \langle N_W \rangle$, $\langle K^+ \rangle / \langle \pi^+ \rangle$, and $T^*(K^+)$. The predicted signature of the deocnfinement transition – the pion kink [1, 7], the strange horn [1] and the step in m_T-slopes [4] are observed simultaneously in the same domain of collision energies $F = 2 \div 3$ GeV$^{1/2}$. The open symbols correspond to the data in $p+p$ collisions. The right panel shows the prediction of SMES for $R_{s/e}$ (8) constructed from fluctuations of strange and non-strange hadron multiplicities [6]. A pronounced minimum of $R_{s/e}$ is predicted in the collision energy domain in which deconfinement transition is located.



The anomalies in the energy dependence of the hadron production are seen in central A+A collisions and absent in the data of $p+p$ reactions. They indicate that the onset of the deconfinement in central Pb+Pb collisions is located at about 30 A·GeV. The theoretical picture is however far from being complete. It seems that the Landau-type initial conditions are not appropriated to describe both the multiplicity and transverse momentum data at the same time. The initial conditions with spatially spread energy and longitudinal velocity distributions are needed to reproduce all main features of the data simultane-

ously [14]. The analysis of the data from the energy scan program is also still in progress. In particular, first results at 20 A·GeV are soon expected. We hope that the properly analysed event–by-event fluctuations (see Ref. [5]) may also be sensitive to the onset of the deconfinement. Especially promising looks a new measure $R_{s/e}$ (8) constructed from the fluctuations of strange and non-strange hadron multiplicities [6] and shown in the right panel of Fig. 5.

Acknowledgements. The results presented in this report were obtained thanks to my close collaboration with Marek Gaździcki. I would like to thank him for a fruitful period of joint work. I am also thankful to Walter Greiner for his permanent support and encouraging of these studies.

References

[1] M. Gaździcki and M. I. Gorenstein, Acta Phys. Polon. **B 30**, 2705 (1999) [arXiv:hep-ph/9803462].

[2] S,V. Afanasiev et al (NA49 Collaboration), Phys. Rev. **C 66**, 054902 (2002).

[3] V. Friese et al (NA49 Collaboration), nucl-ex/0305017.

[4] M. I. Gorenstein, M. Gaździcki and K. Bugaev, Phys. Lett. **B 567**, 175 (2003) [arXiv:hep-ph/0303041].

[5] M. Gaździcki, M. I. Gorenstein and St. Mrówczyński, hep–ph/0304052.

[6] M.I. Gorenstein, M. Gaździcki and O.S. Zozulya, hep-ph/0309142.

[7] M. Gaździcki, Z. Phys. **C 66**, 659 (1995) and J. Phys. **G 23**, 1881 (1997).

[8] L. Van Hove, Phys. Lett. **B 118**, 138 (1982).

[9] C.M. Hung and E. Shuryak, Phys. Rev. Lett. **75**, 4003 (1995).

[10] C.M. Hung and E. Shuryak, Phys. Rev. **57**, 1891 (1997).

[11] D. Teaney, J. Lauret and E.V. Shuryak, Phys. Rev. Lett. **86**, 4783 (2001) and nucl–th/0110037.

[12] M. I. Gorenstein, K. Bugaev, M. Gaździcki, Phys. Rev. Lett. **88**, 132301 (2002), Phys. Lett. **B 544**, 127 (2002), Phys. Rev. **C 68**, 01790 (2003).

[13] M. Gaździcki, M. I. Gorenstein and St. Mrówczyński, Eur. Phys. J. **C 5**, 129 (1998).

[14] M. Gaździcki, M.I. Gorenstein, F. Grassi, Y. Hama, T. Kodama, O. Socolowski Jr., hep-ph/0309192.